Intracranial Time-Resolved Contrast-Enhanced MR Angiography at 3 T

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Introduction

Due to the inherent trade-off between SNR, spatial resolution, and temporal resolution in MRI, limitations are placed on acquisition parameters for demanding applications such as high-resolution time-resolved angiography. While x-ray digital subtraction angiography remains the gold standard for time-resolved angiography, improved contrast-enhanced MR angiograms (CE-MRA) would still be of clinical utility because they are noninvasive and 3D. With the development of 3 T clinical MR scanners, the expected doubling of SNR compared to 1.5 T scanners suggests that angiography could be improved at higher field. The increase in main field strength comes at the expense of increased specific absorption rate (SAR), however, which becomes a limiting factor at short TR's. We present here a high spatial resolution and temporal resolution CE-MRA technique at 3 T, applied to the intracranial vasculature, for the noninvasive diagnosis of arteriovenous malformations and fistulae. In adjusting acquisition parameters for 3 T, we found that a longer-than-typical TR both increased SNR and allowed higher flip angles to be achieved, further increasing SNR. To compensate for the longer TR and to convert SNR into greater temporal resolution, several undersampling techniques were employed in combination, including partial Fourier, TRICKS (1), and GRAPPA (2).

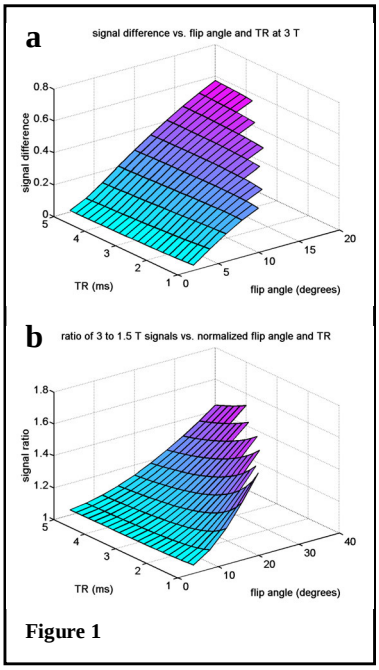

Figure 1

Materials and Methods

In order to determine the optimal imaging parameters at 3 T, simulations were performed to calculate the signal difference between enhanced and non-enhanced blood at 1.5 and 3 T. For the spoiled, steady-state gradient echo sequence, signal, S, was taken to be the steady-state transverse magnetization in the rotating reference frame immediately after RF excitation,

$$S = M_{x'y'}^{ss}(t=0_+) = \frac{M_z^0(B_0)\cdot(1-e^{-T_R/T_1(B_0)})}{1-e^{-T_R/T_1(B_0)}\cos\alpha}\sin\alpha \qquad (1)$$

The equilibrium magnetization was normalized to 1 at 1.5 T, and doubled at 3 T. The T_1 value of contrast-enhanced blood was calculated as $1/T_1 = 1/T_1^0 + \alpha C$, where α the contrast agent relaxivity and C is the intraarterial concentration. The intraarterial concentration was calculated as $C_{IA} = C_{IV}Q/CO$, where C_{IA} is the intraarterial concentration, C_{IV} is the intravenous injected concentration, Q is the injection rate, and CO is cardiac output.

Images were acquired from healthy volunteers and patients with confirmed pathology on 1.5 and 3 T whole body MR scanners (Avanto and Trio, Siemens Medical Solutions, Erlangen, Germany) with a 4-channel head coil on the 1.5 T scanner and an 8-channel head coil on the 3 T scanner (Siemens Medical Solutions, Erlangen, Germany). A sagittal 3D multi-phase FLASH pulse sequence was used with a Cartesian *k*-space trajectory, centric reordering, partial Fourier, TRICKS, and GRAPPA (FOV = 250 × 250 × 75 mm, image matrix = 256 × 256 × 30, spatial resolution = 1.0 × 1.0 × 2.5 mm, phases = 15, temporal resolution = 3.0 s/frame, TR/TE = 3.4/1.3 ms, flip = 20º, bandwidth = 1300 Hz/pixel, R-L/A-P partial Fourier factors = 0.75/0.75, 3 TRICKS segments, GRAPPA acceleration factor/reference lines = 2/24). The scan covered either the left or right half of the head, including the sagittal sinus. A single dose of a gadolinium-based contrast agent (Magnevist, Berlex, Wayne, New Jersey) was administered in an antecubital vein at an injection rate of 4.0 ml/s, starting simultaneously with the imaging protocol. Simulations were confirmed with SNR measurements at 1.5 and 3 T, using only the body coil to best rule out coil-related SNR variation. Images were qualitatively scored by a board-certified radiologist.

Results

Figure 1(a) displays the difference between enhanced and non-enhanced blood signal at 3 T vs. flip angle and TR. Certain combinations of low TR and high flip angle were experimentally determined to exceed the SAR threshold. **Figure 1(b)** displays the ratio of 3 to 1.5 T signals vs. TR and a normalized flip angle yielding equivalent SAR (i.e., a 20º flip angle at 1.5 T results in the same SAR as a 10º flip angle at 3 T). In essence, the graph demonstrates that in SAR-limited cases, SNR still increases by a factor of ~1.5 at 3 T compared to 1.5 T, but not by a whole factor of 2. SNR measurements confirm this result. **Figure 2(a-c)** are sagittal magnitude subtraction MIP's demonstrating the technique in a healthy volunteer at 3 T with a temporal resolution of 3.0 s, and **Figure 2(d-f)** in a patient with an arteriovenous malformation (AVM). Notice the delineation of small cortical vessels. The time-resolved acquisition allows the AVM's draining and feeding vessels to be diffentiated.

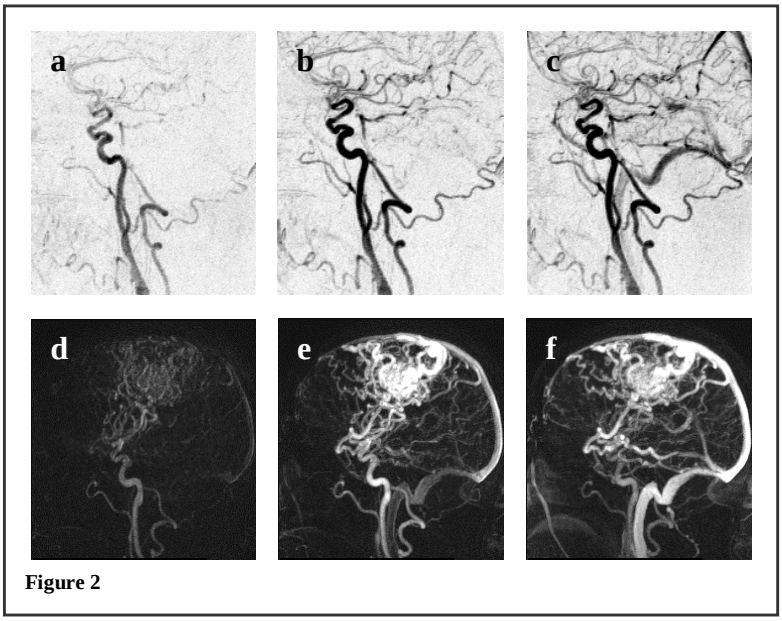

Figure 2

Discussion/Conclusion

Time-resolved CE-MRA is significantly improved at 3 T compared to 1.5 T; however, the acquisition parameters must be modified to account for greater SAR. High acceleration factors allow the SNR boost to be converted into increased temporal resolution for study of flow-related pathologies commonly arising in the intracranial circulation.

References

1. Korosec FR, et al. MRM 1996;36:345-351.
2. Griswold MA, et al. MRM 2002;47:1202-1210.